

HOLOCENE VEGETATION AND ENVIRONMENTAL HISTORY OF CRANBOURNE BOTANIC GARDEN, VICTORIA

D. L. AITKEN AND A. P. KERSHAW

Centre for Palynology and Palaeoecology, Department of Geography and Environmental Science, Monash University, Clayton, Victoria 3168

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The vegetation of the Cranbourne Botanic Garden has shown substantial changes during the Holocene due to the influences of climate, sea level rise, fire and, recently, European people. The earliest recorded phase, prior to 8,500 years BP, was characterised by ephemeral swamps and *Casuarina*-dominated dry-land communities. Climatic amelioration after this time is indicated by the establishment of permanent swamp conditions and an increase in *Eucalyptus* within the regional vegetation. Highest available moisture levels occurred between about 7,000 and 5,000 years ago as a result of increased effective precipitation and the attainment of high sea levels towards the end of the post-glacial marine transgression. *Casuarina* communities declined abruptly and were partially replaced by tall open eucalypt forests with a substantial amount of the wet sclerophyll taxon *Pomaderris* in the understorey. Increased climatic variability and burning within the last 5,000 years has led to the development of a diverse vegetation dominated by sclerophyll woodlands and heath which has been subsequently modified by European activities. These changes provide some basis for understanding the present nature and stability of the vegetation and should contribute to the formulation of future management practices.

IN 1970, the Royal Melbourne Botanic Gardens established an annexe at Cranbourne, now called the Cranbourne Botanic Garden, expressly for the purpose of cultivating and researching Australian native plants (Martin 1981, Pescott 1982). The annexe also incorporated a large, relatively undisturbed area of native heathland and *Eucalyptus* woodland, an important remnant of the vegetation that once covered an extensive area prior to clearing for agriculture and mining. The remnant vegetation provides the opportunity to conduct ecological research on *in situ* populations that could lead to the improvement of techniques for managing natural communities (Ashton 1987). The present project was designed to determine the current status of the vegetation from an examination of its history, providing information that might be of use in future management strategies. Specifically, the project involved the pollen analysis of accumulated swamp sediments within the Garden.

THE STUDY AREA

The Garden covers an area of approximately 350 hectares, 2.5 km to the south of the rapidly expanding township of Cranbourne at the extreme north of the Mornington Peninsula. The

site is 50 km south-east of Melbourne and approximately 15 km from the shores of both Port Phillip Bay and Western Port (Fig. 1).

The Cranbourne region is located in an area of Mediterranean climate with a maritime influ-

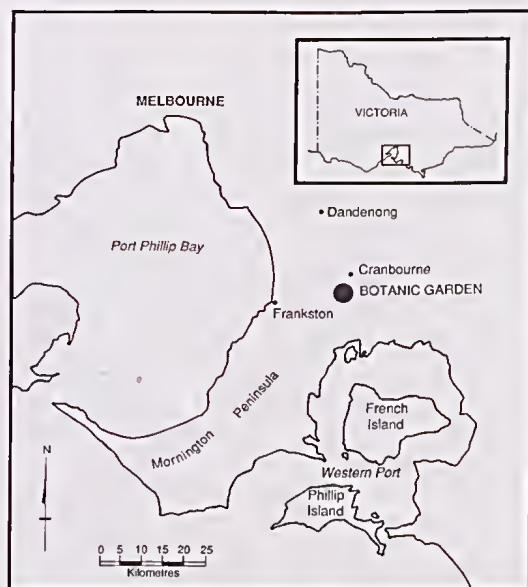


Fig. 1. Location of the study area.

ence (Conservation, Forests and Lands 1986, Pike & Calder 1978). Estimates from the climatic prediction system BIOCLIM (Booth et al. 1987) indicate that the garden receives an annual mean rainfall of about 800 mm of which 230 mm falls in the winter quarter and 160 mm in the summer quarter. The annual mean temperature is about 14° C, with a mean maximum temperature in the warmest month of 25° C and a mean minimum temperature in the coldest month of 6° C. Occasional winter frosts are experienced, and summer temperatures can exceed 30° C (Pike & Calder 1978). Winds are predominantly from the west and south-west quarters, tending from the north-west in summer.

The Garden lies about 60 m above sea level on a plain of low relief (Marsden et al. 1979). Most of the Garden is located on the Cranbourne Sand, a Pleistocene sand dune deposit, while Silurian siltstones and mudstones outcrop in the southern part. The well-drained dune crests support dry sandy podzols while the depressions, which are frequently seasonally wet, have humic podzol soils (Gullan 1978, Holmes et al. 1940). During high rainfall periods, temporary steams may develop in the interdune swamp areas. Loams, sandy loams and clay loams are the characteristic soil types on the Silurian rock areas.

Regionally, the vegetation was dominated by *Eucalyptus* forest and woodland before European settlement. To the north and north-east of the Garden were eucalypt woodlands with a grassy understorey (Holmes et al. 1940), while to the south and south-west *Eucalyptus cephalocarpa*, *E. radiata* and *E. viminalis* dominated open woodlands and open forests with *E. ovata* and *Melaleuca ericifolia* and/or *M. squarrosa* predominating in depressions or along streamlines (Calder 1975). Wet sclerophyll forest elements such as *Pomaderris aspera*, *Olearia argophylla*, *Cyathea* and *Dicksonia* occurred to the north in the Dandenong Ranges and in sheltered gullies in the southern part of the Mornington Peninsula, while forests of *Banksia integrifolia* and *Casuarina stricta* were extensive in coastal areas. Indigenous vegetation today comprises only 15% of the land surface of the Mornington Peninsula (Calder 1975).

Gullan (1978) described and mapped the vegetation occurring predominantly on the Cranbourne Sands within the original annexe, before that area was augmented by additional land purchases (see Fig. 2). He identified four major

vegetation units. Unit 1 occurs on well-drained podzolic soils and is characterised by a sparse to dense canopy of *E. viminalis* with a variable understorey of *Leptospermum myrsinoides* and other heath species. On dune crests heath is dominant and *E. viminalis* often adopts a low mallee habit, while on the lower slopes, *E. viminalis* is taller and more abundant, often growing in association with *E. cephalocarpa*. Unit 2 occurs on low lying humic podzols and is dominated by a dense canopy of *E. cephalocarpa* and/or *E. viminalis* with a dense understorey composed of *Melaleuca squarrosa*, *Leptospermum juniperinum* and *Gahnia sieberana* in drier areas, and *Empodisma lateriflorus*, *Schoenus brevifolius*, *Lepidosperma longitudinale* and *Cassytha glabella* in wetter areas. Unit 3 is found on waterlogged humic podzols which inhibit the development of a tree layer. The dominant species here are the swamp sedges *L. longitudinale*, *Baumea tetragona* and *Chorizandra cymbaria*. On humic clay and other wet clayey soils, dense thickets of *M. squarrosa* predominate above a cover of sedges and rushes including *L. longitudinale* and *Lepyrodia muelleri* (Unit 4).

The original annexe area has been subjected to a number of disturbance factors including cattle grazing from the early 1820s, sand extraction since the early part of the present century and extensive vegetation clearing between 1966 and 1969 (Gullan 1978). Some small areas exist where vegetation is greatly disturbed resulting in mostly unvegetated sand. In the south and south-west the original vegetation has been entirely replaced by pasture. In the north-west, there remains an area of relatively undisturbed *E. radiata/E. cephalocarpa* open forest with an understorey of *Pteridium esculentum* and grasses. This is a remnant of the vegetation that was once widely distributed on Silurian sediments.

Prior to the arrival of Europeans, the region was inhabited by the Bunurong tribe who would have made extensive use of the area now occupied by the Garden, the sand ridges providing useful vantage points in the generally flat terrain and the swamps providing a range of plant and animal food resources (Ellender 1991). A recent brief archaeological survey of the Garden revealed a number of artefact scatters on the dunes surrounding one of the swamp sites used in this study (Ellender 1991).

Two swamp sites, unofficially named Tiger Snake Swamp and Tadpole Swamp on the basis of their most obvious faunal inhabitants, were

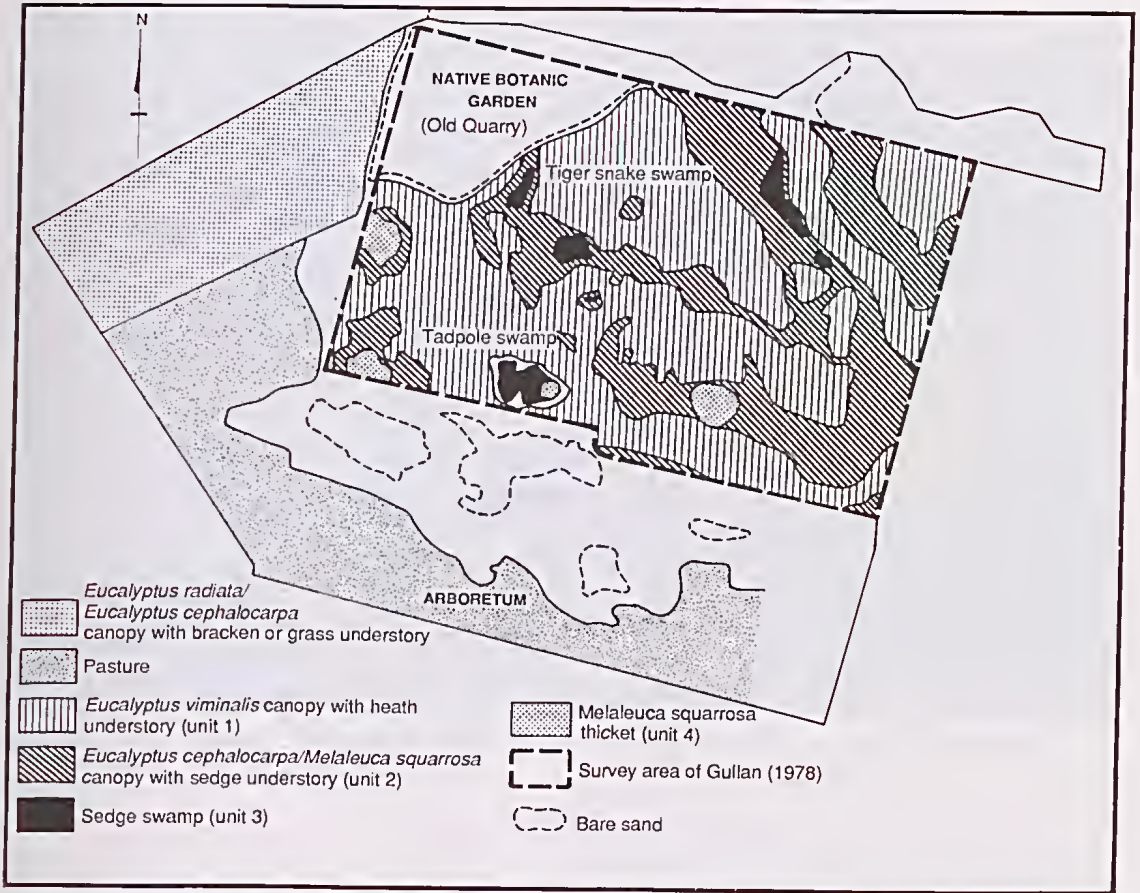


Fig. 2. Location of study sites and distribution of vegetation types within the Cranbourne Botanic Garden (after Gullan 1978; Royal Botanic Gardens aerial photo run 1989).

selected for study after preliminary coring of a number of potential sites in the Garden (Fig. 2).

Tiger Snake Swamp (Fig. 3) lies in an elongated basin approximately 100 m long and 30 m wide, situated to the south-east of a steep ridge of the main sand dune left undisturbed by local mining activities. From coring it was determined that the swamp lies in a shallow sandy depression perched on the clay sediments of the underlying Silurian mudstone. This depression forms a low spot along a more extensive drainage line between the north-west-south-east trending dune and the slightly elevated undulating land to the north-east. When visited in February and October 1990, the swamp contained between 60 and 100 cm of water but it is not known whether the surface dries out on oc-

casions. The swamp vegetation consists of scattered low shrubs of *M. squarrosa* growing out into the water and patchy distributions of species of Cyperaceae including *Lepidosperma longitudinale* and *Banmea tetragona*.

Around the swamp are thickets of *M. squarrosa* that are replaced on the slopes by open woodland of *E. viminalis* and *E. cephalocarpa*, with an understory of *Pteridium esculentum* and heath, and on the ridges by low sandy heath. The sheltered south-facing slope of the dune supports a vigorous growth of *Gleichenia microphylla*, under a canopy of eucalypts on the middle slope and under *M. squarrosa* around the water's edge.

Tadpole Swamp (Fig. 4) is situated in a depression between the main dune ridge and a smaller sand accumulation to the south. The



Fig. 3. Tiger Snake Swamp and surrounding *Melaleuca squarrosa* thicket with *Gleichenia microphylla* and *Eucalyptus viminalis*/*E. cephalocarpa* woodland.



Fig. 4. Tadpole Swamp and surrounding *Melaleuca squarrosa* thicket with *Eucalyptus viminalis*/*E. cephalocarpa* woodland.

swamp is roughly rectangular in shape. Its open area measures approximately 85 m by 35 m, and adjacent *Melaleuca* scrub occupies a similar area. In December 1989 and in February 1990 the swamp surface was dry and cracking, but in October 1990 the basin contained about 1 m of water. From coring it was determined that the swamp lies in a sandy basin, but the underlying mudstone was not penetrated.

The swamp vegetation is very similar to that of Tiger Snake Swamp except for the presence of abundant *Villarsia exaltata* and *Triglochin procera*, and the substantial incursion of *M. squarrosa* over the swamp surface. Open *E. viminialis* and *E. cephalocarpa* woodland with an understorey of *P. esculentum*, *L. myrsinoides* and other heath species occurs on the dune slopes above the *M. squarrosa* thickets, while the upper slopes and dune crest are vegetated with heath, locally dominated by *L. myrsinoides*.

A major recent influence on Tadpole Swamp was a fire in April 1986 that burnt the surface peat and local vegetation, predominantly in the southern half of the swamp. Mining has not directly affected either site but an area immediately to the north of Tiger Snake Swamp and another to the south of Tadpole Swamp have been subject to extensive sand extraction.

FIELD AND LABORATORY METHODS

Core collection

Probing revealed that the deepest penetrable sediments occurred close to the centre of Tiger Snake Swamp. A 156 cm long core was extracted with a side filling peat sampler for subsequent analysis. The top 17 cm consisted of material too unconsolidated to be retained in the D-section sampler. This surface sediment was sampled with a PVC tube and stored in a freezer to prevent sediment mixing.

At Tadpole Swamp, probing indicated a depth of at least 2.5 m of penetrable sediment close to the centre of the basin. As the swamp surface was dry, a wide diameter core was collected in an 80 mm diameter PVC tube with the assistance of a piston attached to a tripod, and the core was extracted with a winch mechanism. The core was 241 cm in length.

Sediment description and sampling

In the laboratory, the stratigraphy of cores from both sites was described. Cores were then sampled for analysis by extraction of 1 cm slices

at regular intervals—5 cm for the Tadpole core, 4 cm for the Tiger Snake D-section core, and at contiguous 1 cm intervals for the frozen Tiger Snake core. In the freezer, the 17 cm core had shrunk to 14 cm. One cubic centimetre samples were then extracted from each slice for pollen and charcoal analysis. The remaining material was dried in an oven at 105° C for 24 hours and then ignited in a furnace at 500° C for 2 hours in order to determine moisture and organic contents.

Pollen and charcoal sample preparation

Preparation of samples for pollen and charcoal analysis followed standard methods detailed by Faegri & Iversen (1975). These included potassium hydroxide treatment to break down the sediment and dissolve fine humic material, sieving to remove larger plant fragments and sand, hydrofluoric acid treatment to dissolve silicates, and acetolysis to dissolve additional organic matter and darken the pollen grains to facilitate identification. Prepared samples were mounted on microscope slides in a measured quantity of silicone oil.

Counting and identification

Using an Olympus CHA microscope at 300 × or 600 × magnification, pollen grains were counted along evenly spaced transects across each slide until 150 grains of dry-land plants had been recorded. Identification was generally only possible to the genus or family level, but many fern spores that had lost their exosporia could only be counted as monolete or trilete morphological types. Except for *Leptospermum*, there was difficulty in separating many myrtaceous grains to lower taxonomic levels, so that there may be some overlap in identifications between the broad categories *Eucalyptus*-type, *Melaleuca*-type and myrtaceous shrubs. A distinctive Asteraceae grain with very blunted spines was given its geological form taxon name *Tubulifloridites pleistocenicus* (Martin 1973), while *Myriophyllum* was sub-divided on the number of grain apertures.

All black, opaque, angular particles over 15 μm maximum diameter were deemed to be charcoal derived from the burning of plant material. These were also counted along spaced transects. All samples from Tadpole Swamp and the frozen core from Tiger Snake Swamp were counted but, due to time constraints and the sparse and poorly preserved nature of grains

from the Tiger Snake peat sampler core, only a few samples were examined from there.

Radiocarbon dating

Samples were submitted for dating to the Radiocarbon Laboratory, University of Waikato. Initially, samples were selected from the bases of the more organic-rich sediments in each core, i.e. 160–156 cm at Tadpole Swamp and 70–69 cm at Tiger Snake Swamp. Subsequently, samples were submitted from depths of 105–100 cm and 65–60 cm in the Tadpole Swamp core in order to date significant changes in the pollen record.

POLLEN DIAGRAMS

Tadpole Swamp (Fig. 5)

The Tadpole Swamp diagram has been divided into zones on the basis of major changes in representation of dry-land pollen taxa. Pollen and charcoal concentrations vary dramatically through the sequence. Pollen concentrations tend to peak at or close to zone boundaries while highest values for charcoal occur at the very base of the sequence and in Zone T4.

Zone T1 (200–160 cm), > c. 8,500 BP. The pollen record begins where organic matter in the form of macroscopic plant remains becomes visible within the basically sandy sediments. Throughout the zone both moisture and organic contents of the sediment are low. Aquatic pollen is dominated by three taxa, *Melaleuca*-type, Cyperaceae and *Haloragis*, with Restionaceae, *Typha*, *Sphagnum* and *Tiletia*, the fungal associate of *Sphagnum* being less common or rare. *Baumea* appears close to the top of the zone. Dry-land pollen is dominated by *Casuarina*, with *Encalyptus*-type, *Leptospermum*, Poaceae and *Trachymene* having moderate values. The only other taxa with a notable presence are myrtaecous shrubs, Asteraceae (Tubuliflorae), *Tubulifloridites pleistocenicus*, Chenopodiaceae and trilete fern spores.

Zone T2 (160–100 cm), c. 8,500–7,000 BP. At the base of this zone there is a sharp increase in both moisture and organic contents of the sediment, and peat becomes the dominant sediment type. Within the aquatic assemblage *Baumea* is the most important taxon. Restionaceae values have increased, while *Melaleuca*-type, Cyperaceae and particularly *Haloragis* have significantly reduced percentages. *Myriophyllum* has its only occurrences in this zone. Of the dry-land

taxa, *Casuarina* continues to dominate, with substantially increased values for Poaceae and a slight increase in *Eucalyptus*-type. All other taxa, apart from *Pteridium*, have poor representation.

Zone T3 (100–70 cm), c. 7,000–5,000 BP. There is no change in the nature of the sediments through the zone except for slight declining trends in moisture and organic contents, which continue to decline gradually as far as the sediment surface. Values for Cyperaceae and *Baumea* are generally lower than in the previous zone, while *Melaleuca*-type and Restionaceae increase towards the top of the zone. *Tiletia* shows an isolated large peak at the T2–T3 zonal boundary, while *Sphagnum* shows two high values within the zone. The dry-land taxon *Casuarina* declines dramatically through the zone, while *Encalyptus*-type continues to increase so as to form the major dry-land pollen component. Poaceae maintains its relatively high representation while *Pomaderris* and *Auperea* have their highest values for the diagram. Chenopodiaceae and Asteraceae (Tubuliflorae) have higher representation than in the previous zone and *Leptospermum* and myrtaecous shrub values increase through the zone to levels present in Zone T1. All pteridophyte taxa are poorly represented.

Zone T4 (70–0 cm), c. 5,000–present. The aquatic pollen record is dominated by *Melaleuca*-type, *Baumea*, Restionaceae and *Sphagnum*, with Cyperaceae decreasing towards the surface to its lowest levels for the diagram. *Haloragis* almost disappears after a relatively high value in the basal sample, while *Villarsia* is consistently present in the upper part of the zone. *Leptospermum* is the dominant dry-land taxon, while *Encalyptus*-type declines abruptly at the T3–T4 zonal boundary. *Casuarina*, *Encalyptus*-type and Poaceae are moderately abundant. *Plantago* (native) and *Monotoca* are consistently present for the first time, the latter together with *Pomaderris* achieving high values in the top two samples. Pteridophytes are better represented than in lower zones, with both *Pteridium* and trilete fern spores having occasional high values. The presence of *Pinus* in the top sample suggests that this sample falls within the period of European occupation.

Tiger Snake Swamp (Fig. 6)

D-section core sequence (80–20 cm). The pollen record begins above the basal clay and the lower part of the organic sand. Initially both water and

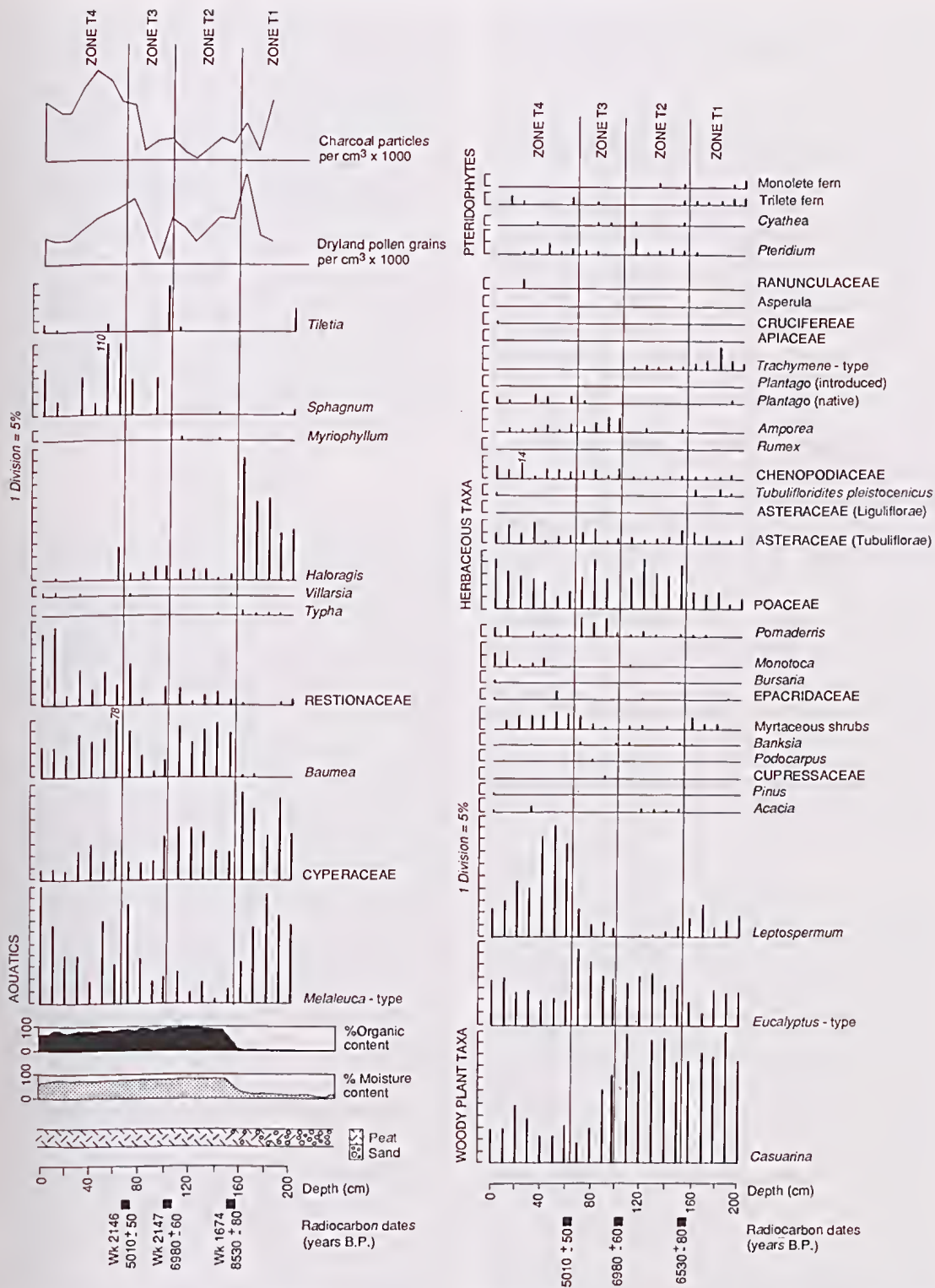


Fig. 5. Pollen diagram from Tadpole Swamp. Values for all pollen taxa expressed as percentages of the native dry-land plant pollen sum for each sample.

organic contents are very low, but water content increases from about 60 cm to the surface and organic content becomes marginally higher in the top 40 cm.

The pollen spectra have high representation of a number of aquatic taxa. *Melalencia* achieves extremely high values in the interval before the radiocarbon date of 5,500 years BP, whereas Restionaceae and *Sphagnum* peak after this time. *Typha*, *Myriophyllum* and *Haloragis* show consistent representation while *Villarsia*, *Triglochlin* and *Tiletia* are present at some levels. Pore number variation in *Myriophyllum* appears extremely variable but this is caused largely by very low pollen representation in some samples. In general terms, the proportion of 5–7 pored specimens decreases through the sequence.

Dry-land pollen spectra are dominated by *Casuarina* except in two samples around the date of 5,500 BP where *Eucalyptus* achieves highest values. Other well represented taxa include Poaceae, *Leptospermum*, *Pteridium* and Asteraceae, with both Asteraceae (*Tubuliflorae* and *Tubulifloridites pleistocenicus*) peaking along with *Eucalyptus* at the expense of *Casuarina* at 70 cm. Epacridaceae, *Pomaderris*, myrtaceous shrubs, *Monotoca*, Chenopodiaceae, *Amperea*, *Plantago* (native), Cruciferae, *Gleichenia* and trilete spores are the only other taxa with more than a single occurrence. *Pinus* is present in the top sample.

Pollen concentrations are relatively consistent through most of the sequence but decline substantially towards the top and were insufficient to obtain a statistically meaningful count at 28 cm. Charcoal values fluctuate throughout.

Frozen core sequence (14–0 cm). Moisture and organic contents are generally higher than in the D-section core and the closer sampling interval allows a better assessment of pollen changes. In contrast to earlier spectra, *Myriophyllum* dominates the basal part of this sequence from 14–6 cm, although the other major aquatics *Melalencia*, Cyperaceae, *Banmea*, Restionaceae and *Sphagnum* also have relatively high values. All these taxa together with *Typha* decrease in the uppermost samples, while *Villarsia* disappears. Only *Haloragis* maintains its percentages.

Within the dry-land taxa there is higher diversity than in the D-section core sequence, with a number of native taxa including *Callistemon*, *Banksia*, *Acacia*, Proteaceae, *Leucopogon* and *Dicksonia* being represented for the first time and significant increases in values for *Monotoca*, *Pomaderris*, Chenopodiaceae, *Plantago*

(native), *Cyathea* and other pteridophyte spores. From the basal sample of this sequence, *Casuarina* declines relative to *Eucalyptus* and then falls dramatically in the top three samples. This fall is accompanied by a substantial increase in Poaceae and a lesser increase in *Leptospermum*. *Pteridium* also declines in the top samples while *Gleichenia* increases. The impact of Europeans is indicated by relatively high values for the exotics *Pinus*, Asteraceae (*Liguliflorae*) and *Plantago* (introduced), and the probable exotics *Rumex* and *Apiaceae*. There is some indication of the replacement of native *Plantago* by introduced species in the top few samples.

Pollen concentrations are constant at moderate levels while charcoal values increase initially and then decline sharply in the top few samples.

DISCUSSION

Site record correlation

The radiocarbon dates suggest that the Tiger Snake Swamp record may only cover the period represented by Zone T4 and the upper part of Zone T3 in the Tadpole Swamp record. Some additional support for this conclusion is provided by similar changes in some dry-land pollen taxa. *Casuarina* shows a marked decline around the radiocarbon age of 5,000–5,500 BP in both records while Poaceae values dip after this level in both diagrams. There are also marked differences between the two records, however, particularly in samples dating older than 5,500 BP. In these samples, the record from Tiger Snake Swamp has much lower values for *Eucalyptus* and Asteraceae, and higher percentages for *Leptospermum* and *Pteridium*, in these respects more closely resembling lower samples from Tadpole Swamp. Similarly, the high values of *T. pleistocenicus* at the base of the Tiger Snake Swamp core suggest an age older than 8,500 BP, although this is not supported by the relatively high values for *Amperea*. It is possible that hiatuses may be present in the Tiger Snake Swamp record or that there has been mixing of the older sediments. Alternatively, there may have been a high degree of heterogeneity in the vegetation and differential response to environmental changes, thus inhibiting clear biostratigraphic correlation. The aquatic taxon values in the two records differ considerably, preventing correlation on those data.

The first appearance of *Pinus* is noted in the top sample of Tadpole Swamp and at 20 cm

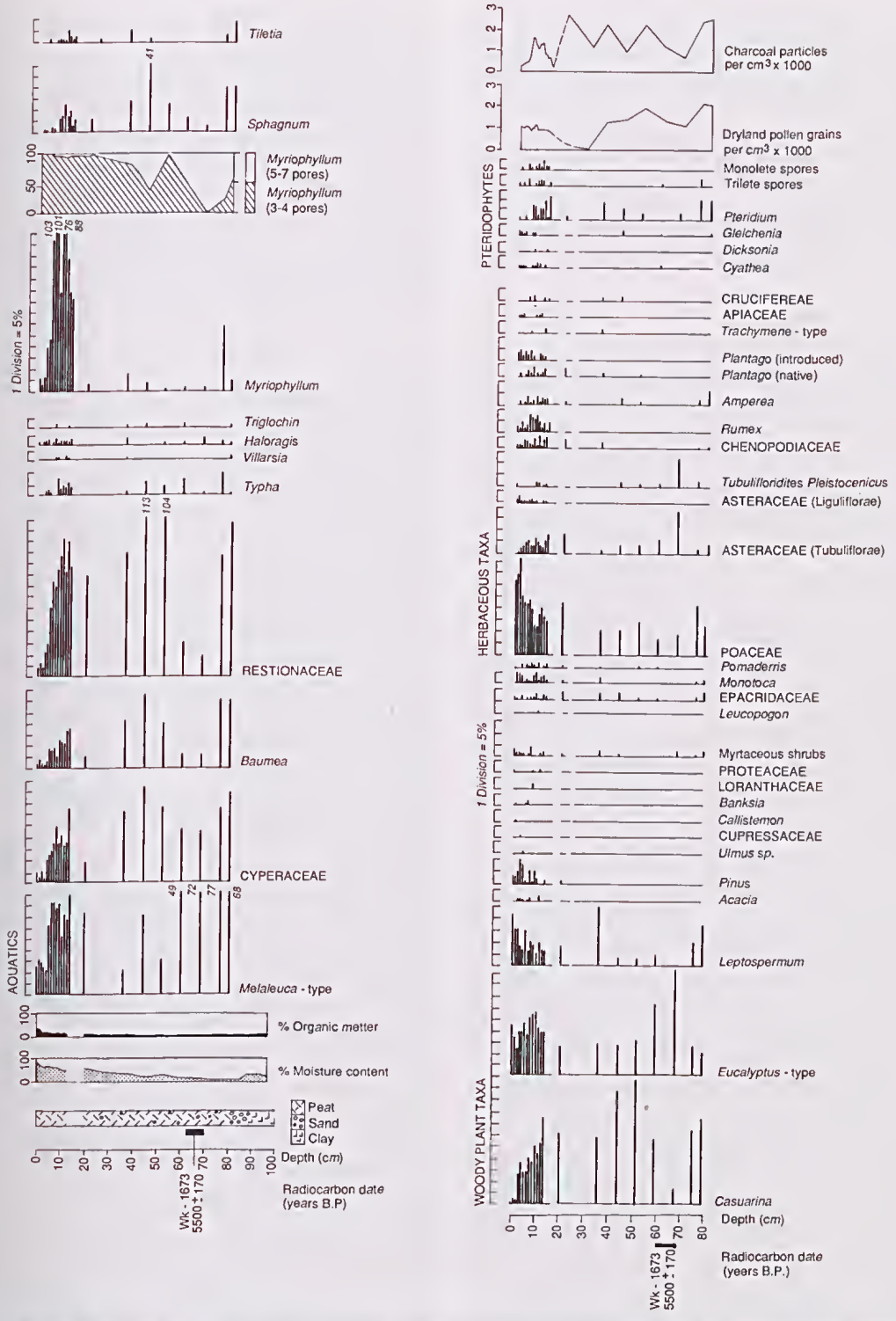


Fig. 6. Pollen diagram from Tiger Snake Swamp. Values for all pollen taxa expressed as percentages of the native dry-land plant pollen sum for each sample.

depth at Tiger Snake Swamp. It is thus likely that there has been little sediment accumulation since European settlement, or that those sediments were burnt in the fire of April 1986 at Tadpole Swamp.

For the purpose of vegetation and environmental reconstruction, most attention will be paid to the more detailed record from Tadpole Swamp for the pre-European period, and to the frozen core record from Tiger Snake Swamp for the European phase.

The hydrosere record

Organic sedimentation in Tadpole Swamp commenced in the early Holocene, probably between 10,000 and 9,000 years ago. Before that time conditions were likely to have been too dry to support swamp or open-water environments. During the early Holocene, precipitation had increased sufficiently to allow the formation of a swamp supported directly by precipitation or, more likely, by a rise in the regional water table resulting from the wetter conditions. The combination of high values for Cyperaceae, *Haloragis* and *Melaleuca*-type indicates an herbaceous swamp surrounded by *Melaleuca* thickets. The inorganic nature of the sediments suggests some environmental variability, most probably regular drying of the swamp surface causing oxidation of accumulated organic sediments. It is also possible that there was still some sand mobility under an incompletely vegetated dune cover.

Permanently wet conditions are indicated after 8,500 BP with the accumulation of organic-rich sediments. Water levels increased, reducing the extent of marginal *Melaleuca* thicket, and the herbaceous swamp became more diverse with the addition of *Baumea* and Restionaceae. The lack of an inorganic substrate would have limited the extent of *Typha*. It is likely that some open water, colonised by the submerged aquatic *Myriophyllum*, also existed.

About 7,000 BP *Sphagnum*, which had always been present on site, expanded and the herbaceous fen component was reduced. This vegetation change may represent a succession from fen to bog as a result of sediment accumulation, although the change corresponds with a similar change in dry-land vegetation suggesting that regional climatic change could have been a contributing factor. More extensive bog development, combined with expansion of *Melaleuca* from towards the end of the period represented by Zone T3, is more obviously a successional

development, perhaps facilitated by generally drier conditions.

A similar mix of aquatics to that at Tadpole Swamp was present at Tiger Snake Swamp during the period represented in the D-section core, although clear patterns are difficult to discern. The presence of *Myriophyllum* in addition to the various emergent herbs, *Sphagnum* and *Melaleuca* suggests a rather unstable mosaic of open water, fen, bog and thicket. The low organic content of the sediment indicates frequent surface drying which created sufficient instability to prevent any directional successional change.

There are two possible causes of this instability. One possibility is that Tiger Snake Swamp, lying within an old drainage line, has been influenced by intermittent and erosive stream flow. This could explain the relatively high inorganic content of the sediment resulting in dilution of accumulated organic material from the remains of swamp plants, and perhaps the variability in dry-land as well as in aquatic pollen composition. It might also explain why the pollen record dates only from about 6,000 years ago as before that time, when precipitation was likely to have been higher than today, water flow could have prevented deposition or removed the finer organic component of the sediment that included the pollen. An alternative explanation is that the swamp has always been ephemeral, and its drying out at regular intervals would have resulted in oxidation of accumulated organic material. The formation of a swamp environment suitable for pollen preservation might have resulted from a rise in the regional water table as sea level reached its present level about 6,000 years ago. The fact that there has been a similar sediment accumulation rate at both Tiger Snake Swamp and Tadpole Swamp within the last 5,000–6,000 years, despite the very different nature of the sediments, suggests a strong regional water table control over swamp development during this period.

Major hydrological changes appear to have accompanied European arrival. At Tiger Snake Swamp there was a massive increase in *Myriophyllum* pollen. The change in *Myriophyllum* pore ratio also suggests a change in floristic composition. A similar increase in *Myriophyllum* pollen representation since European occupation has been noted elsewhere in Victoria and tentatively attributed to catchment disturbance resulting in increased hydrological variability (Kershaw & Gell 1990). The high pollen percentages of *Myriophyllum* may not indicate a substantial increase in abundance of parent plants

but could result from more frequent swamp drying, as many species of *Myriophyllum* only flower when stranded (Orchard 1986). The parallel decrease in pollen of all aquatic taxa within the top few samples is difficult to interpret. It may reflect increased pollen influx from dry-land vegetation rather than an overall reduction in aquatic plants or their flowering.

There is little evidence of the European phase of Tadpole Swamp but the present abundance there of *Triglochin*, which at Tiger Snake Swamp is only recorded before European occupation, suggests that floristic changes have also taken place here.

The dry-land record

Casuarina was clearly the regional dominant during the early Holocene. Although it is not possible to be certain of component species, the size range of pollen grains represented suggests that the woodland taxa *C. stricta* and *C. littoralis* as well as heath species such as *C. pusilla* and *C. paludosa* were present. It is likely that the major vegetation type was *Casuarina* woodland or forest containing a significant proportion of eucalypts. Low values for low-growing taxa that have significant pollen dispersal, such as Poaceae, Asteraceae, Chenopodiaceae and *Pteridium*, suggest that the understorey was fairly sparse. This kind of vegetation was a feature of much of lowland Victoria during the early Holocene (D'Costa et al. 1989), but the reason for the importance of *Casuarina* as opposed to *Eucalyptus*, the canopy dominant of forests and woodlands today, has not been established. It could be due to the ability of *Casuarina* to colonise faster than eucalypt species after the last glacial period when herbaceous steppe vegetation dominated the region, to a climate that was more suitable for *Casuarina*, or to less intense burning (D'Costa et al. 1989). There is little information in the records from Tiger Snake and Tadpole swamps to help clarify the issue. Prior to 8,500 BP the climate was certainly drier than at present, as indicated by the ephemeral nature of Tadpole Swamp, but *Casuarina* maintained its dominance, albeit with some increase in *Eucalyptus* together with the understorey taxa Poaceae and *Pteridium*, under precipitation levels that were probably as high as those of today until its major decline around 7,000 BP. The charcoal record is much too variable to allow any assessment of the likely role of fire in this *Casuarina* decline.

The lower Holocene around Tadpole Swamp is also characterised by the significant represen-

tation of *Tubulifloridites pleistocenicus* and *Trachymene*-type, and the former survived into the late Holocene, being present in both diagrams within the European phase. Both these taxa are common components of cooler environments, *T. pleistocenicus* frequently dominating glacial assemblages (Kershaw et al. 1991). These taxa may have survived from the last glacial period in this area.

There has been discussion on the likely parent plants of *T. pleistocenicus* (Martin 1986, D'Costa & Grindrod 1991, Macphail & Martin 1991). Only two species, *Calomeria amarantoides* Vent and *Cassinia arcuata* R. Br., have been identified in south-eastern Australia as having the same type of pollen (Macphail & Martin 1991). *C. arcuata* is presently recorded from the Cranbourne Botanic Garden and is almost certainly the pollen source in the surface samples. Whether this species was the parent plant of the older pollen is debatable, as there is a gap in representation of this pollen type even at Tiger Snake Swamp where it appears to extend into the middle-upper Holocene. At no site in south-eastern Australia is *T. pleistocenicus* recorded in more than trace values in recent times, so it would appear that no vegetation analogous to that containing high levels of this taxon from older periods presently exists. Either one or both of the identified extant species had a very different ecology in the past, or other plants which are now extinct were the source of the Pleistocene or early Holocene pollen.

Support for the evidence derived from the aquatic diagram of high water levels between 8,500 and 5,000 BP is provided by reduced values of *Leptospermum* and myrtaceous shrubs, which are likely to have been growing locally as their pollen is poorly dispersed. These may have formed part of the swamp fringe, together with *Melaleuca* which may have retreated as a result of higher water levels. Highest effective precipitation probably occurred between 7,000 and 5,000 years ago with the maximum expansion of the wet sclerophyll taxon *Pomaderris*. This expansion corresponds very closely with a similar peak in *Pomaderris* in diagrams from the Gippsland Lakes (Hooley et al. 1980) and with the period of highest lake levels in the Western Plains volcanic crater lakes, as determined from sedimentological, microfaunal and microfloral evidence (Bowler & Hamada 1971, Dodson 1974, De Deckker 1982).

Abrupt increases in *Amperea* and Chenopodiaceae also occurred around 7,000 years ago. As both these taxa have significant representation

in near-coastal environments, their expansion may have been related to the closer proximity of the sea towards the end of the post-glacial marine transgression. Certainly, sea level stabilisation could have resulted in habitats suitable for salt marsh colonisation and, as the chenopodiaceous dominants of these communities have well dispersed pollen, they could have contributed a significant regional pollen component. *Amperea* is essentially a dune inhabitant that exists today within the Garden. Any effect on its distribution or abundance resulting from the proximity of the sea would have been less direct.

After 5,000 years ago the vegetation became more diverse with increased representation of understorey taxa relative to *Eucalyptus*. As suggested previously, the large increases in *Leptospermum* and myrtaceous shrubs can be explained by an invasion of the swamp surface as a result of lower water tables, but the addition of *Monotoca* suggests a general expansion of heath vegetation. It is likely that the eucalypt canopy became more open with an understorey mosaic of heath, *Pteridium* and grassland. This diversity may have been the result of increased burning as indicated by relatively high charcoal levels. Conditions responsible for more frequent fires may have been anthropogenic or climatic. Archaeologists have argued that there was intensified occupation of Australia, together with increased use of fire, within the last 4,000–5000 years (Head 1989, Hughes & Sullivan 1981), while McGlone et al. (1992) have suggested that increased burning could have been caused by an intensification of El Niño–southern oscillation-related climatic variability accompanied by lower rainfall from 5,000 to 6,000 years ago.

A further increase in disturbance levels is reflected in vegetation changes during the period of European occupation, as indicated in the frozen core sequence from Tiger Snake Swamp. The major feature is the addition of exotics. *Pinus* is probably derived from plantations and other plantings outside the Garden, but a significant proportion of the pollen from *Rumex*, *Plantago* (exotic) and Asteraceae (Liguliflorae) could have been from more local sources. There is some indication that native Asteraceae and *Plantago* are being replaced by their exotic counterparts. Within the native woody plant component, shrubs and small trees of *Acacia*, *Banksia* and *Monotoca* have higher values, indicating an increase in shrub understories of the woodlands, or the replacement of woodlands by shrubland and heath. The general increase in

grasses partially reflects clearing of surrounding vegetation. There is a significant increase in tri-lete and mono-lete fern species, probably due to hydrological changes around the margins of the swamp.

The taxa most adversely affected by European activities appear to be *Pteridium* and *Casuarina*, both of which show a marked decline in the top three samples. The substantial increase in Poaceae in these samples suggests that an acceleration in vegetation clearance has been important, perhaps targeting those communities containing significant proportions of these taxa.

The effect of fire on vegetation changes since European occupation is difficult to gauge. It would appear that burning levels have been reduced from pre-European times, but the generally lower pollen densities suggest that charcoal particle concentrations have been effectively diluted by an increase in the rate of sediment accumulation. The peaks in charcoal at the top of the Tadpole Swamp and Tiger Snake Swamp cores, which record the first evidence of exotics, might be significant. Here, pollen concentrations are low suggesting real increases in charcoal that might indicate intense burning during early days of colonisation. Similarly, the real decrease in charcoal within the top three samples of the Tiger Snake frozen core may reflect the policy of deliberate fire exclusion and may date from the widespread fires of 1939. Accelerated clearing during this period would have assisted fire reduction in that the ignition source area would have been substantially reduced.

CONCLUSIONS

Two sites from the Cranbourne Botanic Garden together provide a record of changing vegetation and environments from about the beginning of the Holocene to the present day. Prior to 8,500 years ago, swamps were ephemeral and the regional vegetation was composed largely of open woodland or forest dominated by *Casuarina*, under effective precipitation levels lower than those of today. Some communities characteristic of the preceding cool dry glacial period may also have survived.

The development of permanent swamp conditions about 8,500 years BP indicates an increase in moisture levels. *Casuarina* was gradually replaced by *Eucalyptus* as the dry-land canopy dominant, with high levels of *Pomadouris* between 7,000 and 5,000 years BP indicating a regional expansion of tall open or wet sclero-

phyll forest under maximum Holocene precipitation. High precipitation and high water table levels after 7,000 years BP may have resulted from the close proximity of the sea as sea level reached almost its present height.

After 5,000 years BP there is evidence for increased climatic variability and for increased burning. The vegetation became more diverse with the addition of a significant heath component. This trend was accelerated under higher levels of disturbance resulting from the impact of European people.

The record illustrates and helps to refine the dating of a number of features of Holocene environments in Victoria. These include an early domination by *Casuarina* and its subsequent decline, a peak in precipitation and maximum *Pomaderris* expansion in the mid-Holocene, and increased climatic variability and/or disturbance to the vegetation in the late Holocene.

The record might also contribute to future management of the indigenous vegetation of the Cranbourne Botanic Garden. It illustrates that the vegetation, both aquatic and dry-land, responds markedly to changes in climate, and this has major implications for likely future changes under predicted Greenhouse climates. The general trend throughout the Holocene has been one of increasing diversity which has never been higher than at present. Much of this diversity has resulted from relatively high levels of disturbance reflected mainly in the form of increased burning, and clearly fire must be seen as an integral part of any management strategy. Particular care must be taken to protect some components of the system that have declined substantially in recent times. These components include *Casuarina*, which must be regarded as having relict status, and native *Plantago* and *Asteraceae*, which appear to be being replaced by exotic relatives.

Further useful information that would contribute to an assessment of the present status of the vegetation and its future management could be obtained by a temporally precise palynological study of the last few hundred years, incorporating refined taxonomic identification, charcoal counting and dating methods.

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